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# Soft-decision Viterbi Decoding with Diversity Combining

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## ABSTRACT

Diversity combining methods for convolutional coded and soft-decision Viterbi decoded channels in mobile satellite communication systems are evaluated and it is clarified that the pre-Viterbi-decoding maximal ratio combining shows better performance than other methods in Rician fading channels by computer simulation. A novel practical technique for the maximal ratio combining is proposed, in which the coefficients for weighting are derived from soft-decision demodulated signals only. The proposed diversity combining method with soft-decision Viterbi decoding requires simple hardware and shows satisfactory performance with slight degradation of 0.3dB in Rician fading channels compared with an ideal weighting scheme. Furthermore, this diversity method is applied to trellis coded modulation and significant Pe performance improvement is achieved.

## 1. INTRODUCTION

In a mobile satellite system, a radio terminal must stably operate in a quite low C/N and Rician fading environment. To improve bit error probability in low C/N satellite link, soft-decision Viterbi decoding has been widely adopted as a maximum likelihood decoding for a convolutional code in AWGN (additive white Gaussian noise)(1). On the other hand, to overcome fading in a radio channel, diversity combining has been used for mobile communication and microwave transmission, and recently it is considered to be applied to mobile satellite communication systems(2). Therefore, more improvement is expected in a Rician fading channel using soft-decision Viterbi decoding together with diversity techniques.

In previous studies on Viterbi decoding with diversity combining, several methods have been considered for various systems. For example, selection diversity in(3) or after(4) Viterbi decoding was investigated for Rayleigh fading channel in portable radio communication systems, where Viterbi decoding uses hard-decision signals. In the case of using soft-decision Viterbi decoding, it is possible to adopt maximal ratio combining before decoding(5).

In the first part of this paper, the performances of the following three methods, (a)post-Viterbi-decoding selection, (b)selection in ACS function of Viterbi decoder, (c)pre-Viterbi-decoding maximal ratio combining, are evaluated by computer simulation. As a result, it is clarified that the third method shows more improvement in bit error probability than the others. In the second part, a novel practical technique for the third method, that is maximal ratio combining, is proposed. In the proposed technique, the coefficients for weighting are derived from soft-decision demodulated signals only. The proposed diversity combining method with soft-decision Viterbi decoding requires simple hardware and shows satisfactory performance with a slight degradation of 0.3dB in Rician fading channels from ideal weighting. Furthermore, this diversity method is applied to trellis coded modulation and significant Pe performance improvement is achieved.

## 2. COMPARISON OF DIVERSITY COMBINING METHODS

Three methods for soft-decision Viterbi decoding with diversity combining are investigated and their performances are evaluated by computer simulation.

### (1) Post-Viterbi-decoding Selection

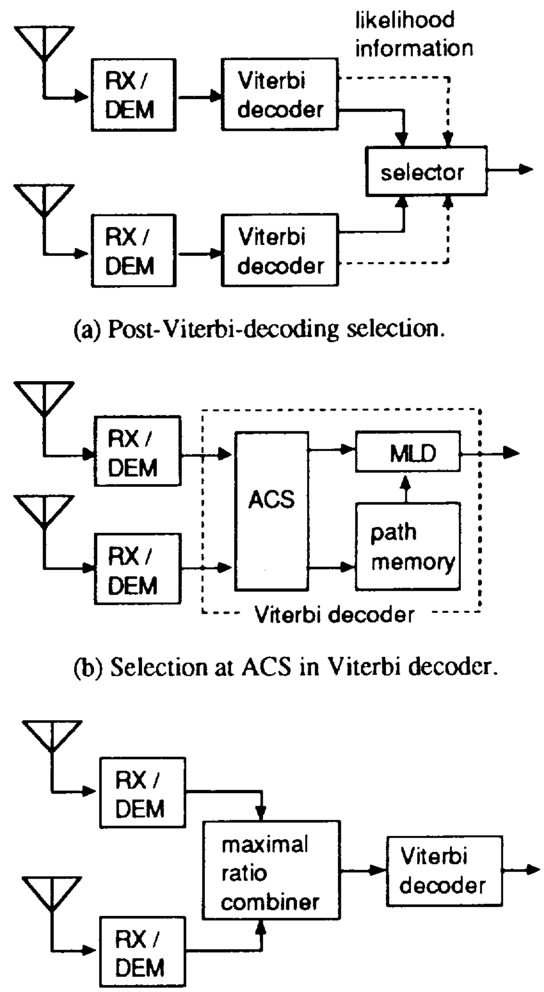
In this method shown in Fig.1(a), each signal received by diversity is individually demodulated and Viterbi-decoded. And then, decoded results are compared and selected based on the likelihood information such as path metrics provided in a Viterbi decoder. In this simulation, path metrics of the last 100 symbols are adopted as the most likelihood information for selection.

### (2) Selection in ACS Function of Viterbi Decoder

In a Viterbi decoder, the branch metrics associated with the state transitions are computed and then added to previous path metrics. The contending path metrics are compared and the path with the largest metrics is selected as a survivor. In this diversity method shown in Fig.1(b), the path metrics are computed for each diversity branch, and then compared all together at one time to select only one survivor. Therefore, this method has only one set of path-history storage.

### (3) Pre-Viterbi-decoding Combining

In the last method shown in Fig.1(c), conventional post-detection combining is applied to soft-decision Viterbi decoding. Soft-decision demodulated signals from each diversity branch




(a) Post-Viterbi-decoding selection.



(b) Selection at ACS in Viterbi decoder.



(c) Pre-Viterbi-decoding combining.

Fig.1 Combining methods in consideration.

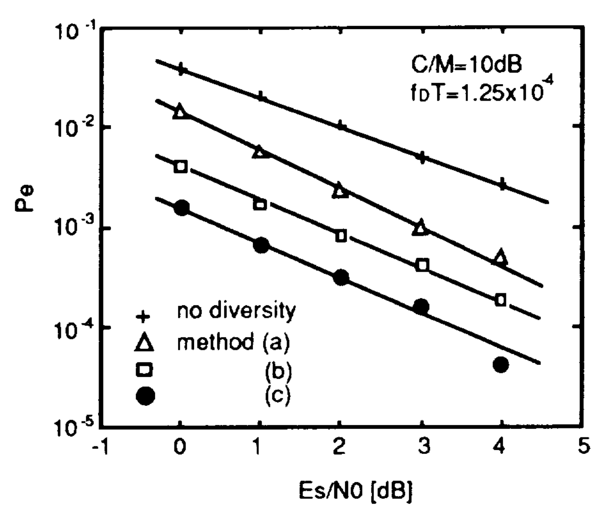



Fig.2 Comparison of combining methods with bit error probability.

are weighted for maximal ratio combining in proportion to signal to noise power ratio, and then summed. After that, they are decoded by a usual Viterbi algorithm.

The performances of the above three methods in a Rician fading channel are evaluated for QPSK coherent detection, convolutional coding and Viterbi decoding (r=1/2,K=4) by computer simulation. Simulation results on Pe performances are shown in Fig.2. In this comparison, Rician parameter C/M (the ratio of direct path signal power and diffused signal power) is set to 10dB and $f_D T$ ($f_D$ : maximum Doppler frequency, T : symbol period) is set to $1.25 \times 10^{-4}$. It is clarified that the method (c), pre-Viterbi-decoding combining, shows better Pe performance than the others. Similar results are obtained for other Rician parameters.

## 3. PRACTICAL COMBINING TECHNIQUE USING SOFT-DECISION SIGNALS

A novel practical technique for pre-Viterbi-decoding maximal ratio combining (method (c)) is proposed. The block diagram of proposed method is shown in Fig.3.

In the case of 2 branch diversity, maximal ratio combining signal $R_{mc}$ is given by

$$R_{mc}=r_1 s_1/\sigma_1^2+r_2 s_2/\sigma_2^2 \qquad (1)$$

where $r_i$; demodulated signal, $s_i$; signal voltage, $\sigma_i^2$; noise power, i (=1,2); branch number.

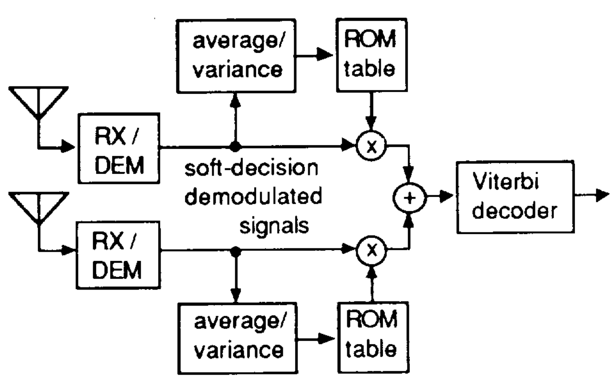



Fig.3 Weighted combining method using soft-decision demodulated signals.

In the proposed method, $s_{ik}$ and $\sigma_{ik}^2$, which are coefficients for weighting at t=kT (T: symbol period), are estimated by calculating the average and variance of absolute value of soft-decision demodulated signals for n symbols from k-n/2 to k+n/2. In low C/N region, estimation error caused by absolute calculation is not negligible, therefore $s_{ik}$ and $\sigma_{ik}^2$ are corrected by referring the ROM table.

## 4. PERFORMANCE OF PROPOSED METHOD IN RICIAN FADING CHANNEL

The performance of proposed method in a Rician fading channel depends on n, the number of observed symbols and $f_D$, maximum Doppler frequency. In an AWGN channel, theoretical improvement in bit error probability performance is obtained by calculating weighted coefficients, $s_{ik}$ and $\sigma_{ik}^2$ for enough symbols. In Rician fading channels with higher maximum Doppler frequency, however, fast change of received level can't be followed if n is too large.

Relation between n, the number of observed symbols, and bit error probability in Rician channels is shown in Fig.4, where C/M=10dB and $f_D T$ is $1.25 \times 10^{-3}$, or $5 \times 10^{-3}$. The smaller n is

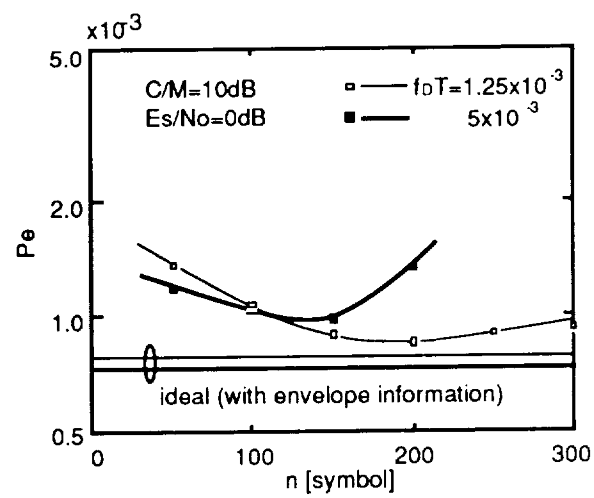



Fig.4 Relation between the number of observed symbols and bit error probability.

(shorter observation), the worse bit error probability is, because of estimation error by thermal noise fluctuation, and the larger n is, the worse it is also, because of slow response for $f_D$. From Fig.4, n=150 is optimum for $f_DT=5\times10^{-3}$, and it also shows enough performance for $f_DT=1.25\times10^{-3}$, which correspond $f_D$ of 40Hz and 10Hz, respectively at a bit rate of 8kbps.

Improvement of bit error probability by the proposed diversity method in a Rician fading channel with C/M of 10dB and $f_DT$ of $5\times10^{-3}$ is shown in Fig.5 (n=150). The performances with ideal maximal ratio combining and equal gain combining are also shown in Fig.5. The proposed method shows satisfactory Pe performance with improvement more than 1dB compared with equal gain combining, and with slight degradation less than 0.3dB compared with ideal maximal ratio combining.

Up to the above section, received signals of two diversity branches in a Rician fading channel are supposed to have no correlation. In practical use, however, two diversity antennas can't be set up at the position with no correlation. In previous report(6) on sea surface reflection fading, coefficient of correlation is about 0.3 when two antennas are placed separating each other by a few times of wave length in vertical direction.

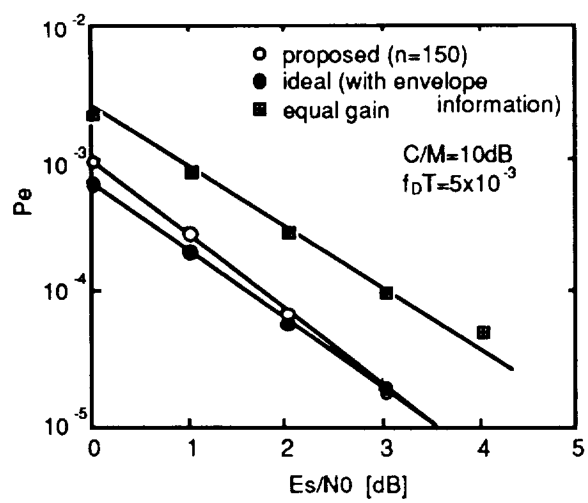



Fig.5 Bit error probability in a Rician fading channel with proposed diversity method.

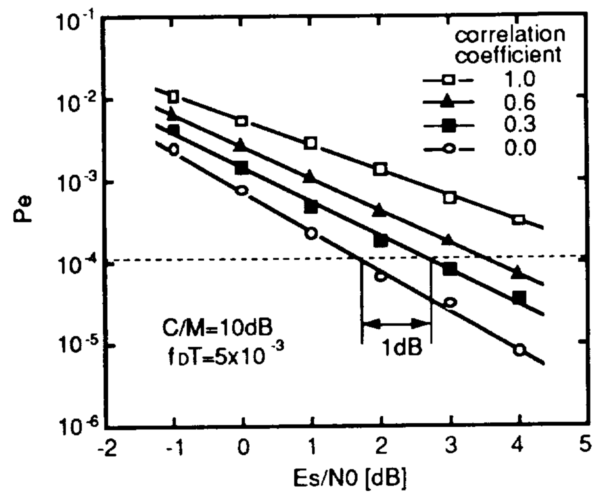



Fig.6 Relation between diversity improvement and correlation of fading.

The relation between improvement with diversity and correlation of fading is shown in Fig.6, where other parameters are as same as those in Fig.5. As seen from this figure, improvement with diversity degrades less than 1dB when correlation coefficient is less than 0.3 at $Pe=1\times10^{-4}$. Therefore, this diversity method is effective in practical use such as under sea surface reflection fading.

## 5. APPLICATION TO TRELLIS CODED MODULATION

The proposed diversity method is applied to trellis coded modulation. In the conventional convolutional coding and Viterbi decoding, branch metrics are calculated based on Hamming distance. On the other hand, in coded modulation, it is on Euclidean distance. Therefore, maximal ratio combining for coded modulation is realized by weighting received signals in modulation-signal space, that is in Euclidean distance, instead of in soft-decision signals, that is in Hamming distance.

Simulation results of 8TCM (octal trellis coded modulation) using 16 states Ungerboeck code(7) with the proposed diversity method is shown in Fig.7, where C/M=10dB, $f_DT=8\times10^{-3}$.

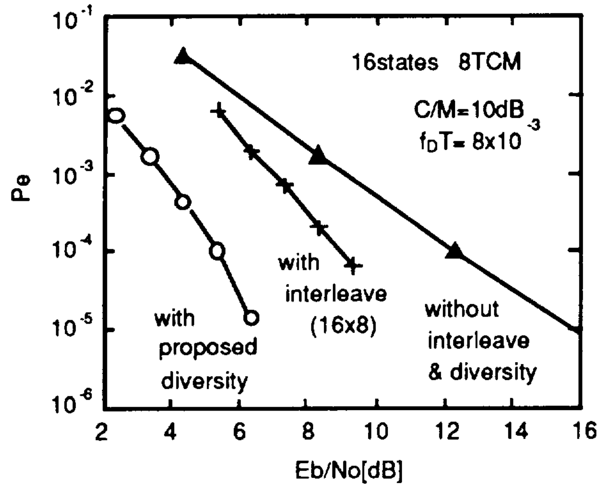



Fig.7 Bit error probability of 16 states 8TCM with proposed diversity method.

In this simulation, ideal CSI (channel state information) is assumed. The results without diversity but with interleave (16x8 symbols) and without both diversity and interleave are also shown in this figure. Improvement of required $E_b/N_0$ at $Pe=1x10^{-4}$ with the proposed diversity is 7dB compared with no diversity and no interleave, and even 3.5dB compared with no diversity but with interleave.

## 6. CONCLUSION

In this paper, it is clarified that the pre-Viterbi-decoding maximal ratio combining shows better performance than other methods in Rician fading channels by computer simulation, and a new simplified maximal ratio combiner using soft-decision demodulated signals is proposed. The proposed method requires simple hardware and effective improvement of bit error probability is obtained in Rician fading channels. Furthermore, it also shows significant Pe performance improvement, where it is applied to trellis coded modulation.

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